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Automatic Contrast Focusing with Three Optical Paths

The invention relates to a method for determining the distance from a point of an object to a specified reference point such as a sensor by measuring contrast values of the point that is represented in the working plane of the sensor, in particular for a scanning profile determination of a material surface with a coordinate measuring instrument, wherein an optical system, which comprises the sensor and is arranged in a probe that is displaceable relative to the object surface, is adjusted in relation to the object, and wherein from the position of the optical system in relation to the object, the distance and/or its profile is determined, wherein in the imaging beam path of the optical system the contrast values of the depicted point are measured at the ends of at least two optical paths of different lengths. Furthermore the invention relates to a device for determining the distance from a point of an object to a specified reference point such as a sensor by measuring contrast values of the point that is represented in the working plane of the sensor, in particular for the scanning profile determination of a material surface with a coordinate measuring instrument, wherein an optical system, which comprises the sensor and is arranged in a probe that is displaceable relative to the object surface, is adjusted in relation to the object and wherein from the position of the optical system in relation to the object the distance and/or its profile can be determined, wherein in the imaging beam path of the optical system the contrast values of the depicted point can be measured at the ends of at least two optical paths of different lengths.

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For the purpose of surface analysis of material surfaces, optically scanning measuring systems are used, which operate based on the automatic focusing principle. For example individual automatic focal points are measured based on the contrast method during the scanning process. In order to record complete contours, this method requires long measuring periods. Several seconds are required for each measuring point.

From P. Profos, T. Pfeifer (editors): Handbuch der industriellen Messtechnik [Handbook of industrial metrology], 5th edition, Oldenbourg Publishing Company, Munich-Vienna 1992, p. 455, 456 a method of the kind described at the beginning is known. There, laser distance sensors are used for detecting surface topographies. In the familiar method, light of a laser diode is cast onto the material surface with a collimator and a movable object. The light that is reflected from the surface reaches an optoelectronic focus detector in the form of a modem line via the objective lens, the collimator and a beam splitter. The objective lens follows in dependence upon the surface topography. From its movement, the height profile is determined. One disadvantage of this method consists of the high sensitivity towards property changes of the material surface.

From H. Naumann. G. Schröder: Bauelemente der Optik, Taschenbuch der technischen Optik (Elements of Optical Systems, Pocket Book on Technical Optics), 6th edition, C. Hanser Publishing Company, Munich-Vienna 1992, p. 348, 349, automatic focusing through contrast measurement is known, wherein three optical paths of different lengths are used

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for photometric contrast measurement and a focus position is recognized based on differences in contrast.

From DE-Z: VDI-Z 131 (1989) No. 11, p. 12-16 R.-J. Ahlers, W. Rauh: "Koordinatenmesstechnik mit Bildverarbeitung" (Coordinate metrology with image processing) a coordinate measuring system based on the automatic focusing principle is known, where three-dimensional object measurement can occur through contrast analysis with spatial frequency measurement of data supplied by an image-detecting sensor.

WO 99/53271 describes a method for determining the profile of a material surface by point-by-point scanning with a coordinate measuring device according to the auto-focusing principle, wherein an optical system that is arranged in a probe that can move in relation to the material surface automatically adjusts its distance to the material surface, and wherein from the position of the optical system in relation to the material surface, the profile of the material surface is determined by measuring the photometric contrast in the path of the image rays of the optical system at the ends of two optical paths of different lengths and by adjusting the distance of the optical system such that the measured contrast values are equal or nearly equal. When the probe is moved towards the material surface or away from it, the position of the plane depicted by the optical system changes in relation to the ends of the two optical paths on which the contrast is measured. The amount of each contrast value depends on the distance between the imaging plane of the surface of the material and the ends on which the contrast is measured.

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Equal contrast values occur when the imaging plane has the same distance to the ends of the optical paths. Modifying the probe position in relation to the surface until the measured contrast values are equal leads to exact focusing.

Underlying the present invention is the objective of further designing a method and a device of the above-described kind in such a way that the distance between the object and the reference point such as the optical system or sensor can be determined extremely quickly and accurately, wherein if necessary several points in the plane of the object should be measured simultaneously. At the same time the device should be simplified, and thus the proneness to trouble should be reduced.

With regard to the method, the problem is basically resolved through the fact that in the imaging beam path of the optical system at the end of three optical paths of different lengths contrast distributions of the beams are determined according to the distance to the point of the object that is to be measured through at least one sensor and that a relationship is established between the resulting contrast distributions as well as that for determining the distance between the point to be measured and the reference point contrast values of the point, which is depicted via the at least three optical paths with different lengths, are measured at a specified distance and transformed to previously determined contrast distributions at the end of one of the optical paths.

In particular the invention here provides that a sensor at all times is allocated to each of the optical paths with different lengths. Alternatively, there is the possibility

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of splitting the beam proceeding from the point into the optical paths with different lengths through optical elements that are arranged in front of a sensor. The optical elements can be flat face-plates, which are arranged in a matrix shape, with different thicknesses, through which the beam is split into partial beams of different path lengths.

Furthermore there is the possibility of dividing the sensor into several measuring areas for the purpose of simultaneous distance measurement in different areas of the object.

In particular, it is provided that the respective contrast distribution is adapted to a parabola, wherein its vertex corresponds to the contrast value at which a point is sharply depicted on the working plane of the sensor. By determining the parabola and its vertex, the optical system can then be adjusted to the point so that the point is depicted in a well-defined manner in the working plane. The contrast distributions can additionally be standardized.

In a further development of the invention, the contrast distributions that are assigned to the optical paths with different lengths overlap such that in the measuring area with a distance that is to be measured, contrast values of a minimum number of contrast distributions are determined, which is sufficient for calculating the contrast distribution for the sensor or the optical path for a sharp depiction of the point that is to be measured through the selected optical path onto the sensor. If there is a possibility of depicting optical paths with different lengths on a sensor, then three or more sensors suitable for

measuring contrast values can be arranged such that their working planes run in different positions to the measuring axis.

Image sensors or CCD or multiple-chip cameras can be used as sensors.

The sensor(s) used for measuring the contrast values can be integrated in particular in a coordinate measuring device in order to measure the distance in the Z-direction. It is also possible to couple the sensor with a position control loop of a CNC control system in order to realize a scanning of a surface that is to be measured.

According to the invention, the knowledge that the contrast values measured at different distances between the measuring point and the working plane of a sensor are located roughly on a parabola is utilized, wherein the contrast values at the vertex correspond to the optical distance between the working plane of the sensor and the point at its sharp depiction. When using several sensors, which have different distances to a point that is to be represented, and determining the contrast value curves and standardizing them based on the geometric relation of the sensors or optical paths to each other, then through determination of the contrast values measured in each sensor at a specified distance, the contrast value curve of the sensor, on whose working plane the point is to be depicted sharply, can be calculated due to the previously known relation of the contrast value curves or parabolae to each other. The point to be measured is then in the focusing plane of the optical system allocated to the sensor. After calculating the appropriate contrast value curve, only the

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vertex still has to be determined to be able to obtain the distance that are to be maintained and if need be set between the sensor and the measuring point.

If for reasons of measuring accuracy or the simultaneous determination of geometries in a plane (XY-plane) that does not contain the distance axis Z it is required that the measuring point be sharply depicted on the working plane of the selected sensor as reference point, then in the event that only distance is determined, it is basically not necessary to change the distance between the optical system that contains the sensor or sensors and the object insofar as the determined contrast values are in measuring areas that enable a calculation of a contrast value curve and thus the distance between the sensor allocated to it and the object. Accordingly, only an adjustment in the XY-plane occurs.

Even if beneficially each optical beam path is allocated a separate sensor, a single sensor can also be allocated to all beam paths, wherein the optical paths with different lengths are realized by arranging matrix-like in front of it suitable optical elements such as flat face-plates of different thicknesses.

Optical system and sensor or sensors of course are always adjusted as a unit. If the optical system is designed as a zoom lens, the necessary conversion factors must be taken into consideration as a function of the positions of the lenses that are incorporated in the optical system.

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The possibility of expanding an optical beam path such that three optical paths with different lengths result can also be realized by allowing the optical beam to penetrate a piezo-electric flat face-plate before entering the optical system, with this plate's thickness being adjustable and thus passing through the light beam areas of different thicknesses. It is also possible to allow the light beam to penetrate a rotating disk, which is equipped with several flat face-plates of different thicknesses. Through a photodiode, the sensor can also be triggered externally.

Furthermore the light beam can be directed to a tilting mirror so that the beam path is directed to at least three sensors such as cameras, wherein the distance should be selected such that the desired optical paths of different lengths are provided.

As a further alternative for realizing the method of the invention, the beam path can penetrate a lens package of a zoom lens in order to achieve the same result.

There is also the possibility of allowing the beam proceeding from the point to penetrate a CCD layer with different pixel areas in order to generate optical paths with different lengths.

A particularly beneficial suggestion provides that the camera itself is supported by a piezo-element, on account of which the distance of the camera to be changed in relation to the point that is to be measured in order to achieve three optical paths with different lengths.

With regard to the device, the problem on which the invention is based is essentially resolved through the fact that, in the imaging beam path of the optical system at the

end of at least three optical paths of different lengths, at least one sensor is arranged for determining the contrast distributions of the beams according to the distance to the point of the object that is to be measured. Preferably one sensor each is assigned to each of the optical paths with different lengths. The one sensor can also be allocated optical elements for splitting the beams proceeding from the point into optical paths of different lengths. The optical element can be flat face-plates of different thicknesses, which are arranged in a matrix shape.

A further development provides for the fact that the sensor and/or its working field is divided into several measuring areas for simultaneous distance measuring of different areas of the object. The sensor can be an image sensor or a multiple-chip camera.

Furthermore it is provided that the sensor is coupled with a position control loop of a CNC control system in order to realize point-by-point scanning measurement of a surface of the object.

In order to obtain a beam proceeding from the point in optical paths with different lengths, the sensor can be arranged in front of a piezo-electric flat face-plate, through which the beam penetrates. It is also possible to arrange a rotating disk penetrated by the beam in front of the sensor on which face plates of different thicknesses are arranged.

Furthermore the device can contain a tilting mirror so that the beam path proceeding from the point is directed to at least three sensors. Furthermore the sensor can contain

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a lens package of a zoom lens, which is penetrable by the beam

In order to change the distance of the optical sensor to the point, it can furthermore be arranged on a fastening device that comprises a piezo-element.

Finally, another refinement provides that the beam proceeding from the point penetrates a CCD layer with pixel areas diverging from one another.

Further details, benefits and features of the invention result not only from the claims, the features contained in them - either by themselves and/or in combination - but also from the following description of a preferred embodiment, which is shown in the drawing.

Depicted is:

Fig. 1 a basic representation of a sensor arrangement for determining the distance of a point and

Fig. 2 principal courses of contrast value curves determined with the sensors from Fig. 1.

In order to determine the distance of a point 10 of an object 12 or its surface to a reference point, such as a sensor 14 in the embodiment, which can be an element of a probe of a coordinate measuring device, which is not explained and shown in detail, according to the invention, one uses the knowledge that distance-dependent contrast values, i.e. the entire contrast value course, is located roughly on a parabola. Changing the distance of the sensor 14 to the point 10 to be measured results (as a function of the imaging plane to the working plane) in a contrast value course in the sensor 14 that corresponds to a parabola and

is labeled with the reference number 16 in Fig. 2. For this purpose, a beam path is directed via a lens 18 to the working plane of the sensor 14 in the conventional manner. According to the invention, the sensor 14 is assigned two additional sensors 20, 22, which have different optical distances to the point 10 to be measured. This is accomplished by dividing the beam 20 that is guided to the sensor 14 via beam splitters 22, 24 and deflection elements such as prisms 26, 28 in order to reach the sensors 20, 22, which in turn can run in relation to their working planes also at difference distances to the point 10 that is to be measured. The lens 18 with the deflection devices 22, 24, 26, 28 as well as the sensors 14, 20, 22 form a unit and can, as mentioned above, be a probe of a coordinate measuring device.

In order to be able to determine in the embodiment the distance between the sensor 14, i.e. its working plane, to a point that is to be measured, in the embodiment point 10, from the contrast values, which are determined via the sensors 14, 20, 22 at a specified distance, without requiring that the point 10 be sharply depicted in one of the working planes of the sensors 14, 20, 22, initially the respective contrast value course that is to be measured in the sensors 14, 20, 22 is determined so that measuring curves are obtained, which are shown in Fig. 2, i.e. the parabola 16 of sensor 14 as well as the parabolae 30, 32, which run offset due to the sensors 20, 22 being arranged at different optical distances compared to the sensor 14, wherein the parabola 30 is allocated to sensor 22 and the parabola 32 to sensor 20. This offsetting of the parabolae

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16, 30, 32 with regard to their distance results from the circumstance that the sensors 14, 20, 22 have different sharpness planes, which are labeled in Fig. 1 with the reference numbers 34, 36 and 38.

If consequently the probe, which comprises the sensors 14, 20, 22 as well as the optical system, is adjusted in relation to the point 10 in such a way that this point is located in the sharpness plane 36 of the sensor 20, then a contrast value 40 is obtained, which corresponds to the vertex of the parabola 32. The same applies in relation to the adjustment of the probe to the sharpness planes 34 and 38 of the sensors 14 and 22.

After the contrast curves 16, 30, 32 have been determined and placed into relation with each other, it is now only required to determine the respective contrast values of the sensors 14, 20, 22 at a desired distance of the probe to a point that is to be measured; from these contrast values then the vertex of the sensor, in the embodiment sensor 14, which corresponds to distance Z, and where the point to be measured is sharply depicted on the working plane of the sensor 14, can be calculated immediately. This is explained in Fig. 2. If the contrast values of the measuring point 10 depicted in the sensors 14, 20, 22 are determined at a distance Z1, then measuring values P1, P2 and P3 are obtained, wherein P3 is the measuring value of sensor 14. The measuring value P1 corresponds to the contrast value, which was determined from sensor 22, and measuring value P3 corresponds to the contrast value, which was determined from sensor 20. Since the relationship between the contrast value curves 16, 30,

32 to each other is known, it is now only necessary to allocate to the measuring values P1 and P3 measuring values on the contrast value curve 16 of the sensor 14 so that overall three measuring values P1', P2' and P3' are obtained, which are located on the stored measuring value curve of the sensor 14. All these values allow then the entire measuring value course and thus their vertex P4 to be determined, to which a distance Z is allocated, at which the measuring point 10 is sharply depicted on the working plane of the sensor 14. Thus, the distance Z between the measuring point and the probe can be determined without requiring the probe itself to be adjusted compared to the object in order to measure several contrast values for each sensor 14, 20, 22.

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